Techniques to Enhance the MANET Lifetime

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Techniques to Enhance the MANET Lifetime

Thesis submitted in partial fulfillment

of the requirements for the degree of

Master of Technology

(Research)

in

Computer Science and Engineering

by

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December 2012

Dedicated to my daughter

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Certificate

This is to certify that the work in the thesis entitled ***Techniques to Enhance the MANET Lifetime*** by ***Suchismita Rout*** is a record of an original research work carried out by her under our supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology (Research) in Computer Science and Engineering, National Institute of Technology, Rourkela. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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Acknowledgment

First of all, I would like to express my deep sense of respect and gratitude towards my supervisor Prof Ashok Kumar Turuk, who has been the guiding force behind this work. I want to thank him for introducing me to the field of Wireless Networks and giving me the opportunity to work under him. His undivided faith in this topic and ability to bring out the best of analytical and practical skills in people has been invaluable in tough periods. Without his invaluable advice and assistance it would not have been possible for me to complete this thesis. I am greatly indebted to him for his constant encouragement and invaluable advice in every aspect of my academic life. I consider it my good fortune to have got an opportunity to work with such a wonderful person.

Secondly, I would like to thank my co-supervisor Prof. Bibhudatta Sahoo for his invaluable suggestions, and encouragements during this research period. I also thank Prof. Sanjay Kumar Jena, Prof. Pabitra Mohan Khilar, Prof. Sarat Kumar Patra and Prof. Gopal Krishna Panda for serving on my Masters Scrutiny Committee.

I wish to thank all faculty members and secretarial staff of the CSE Department for their sympathetic cooperation.

During my studies at N.I.T. Rourkela, I made many friends. I would like to thank them all, for all the great moments I had with them.

When I look back at my accomplishments in life, I can see a clear trace of my family's concerns and devotion everywhere. My dearest mother, whom I owe everything I have achieved and whatever I have become; my beloved father, for always believing in me and inspiring me to dream big even at the toughest moments of my life; and my husband and brother; who were always my silent support during all the hardships of this endeavor and beyond.

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Abstract

Now-a-days more and more devices are getting portable. This have encouraged the development of mobile ad hoc networks (MANET). In addition to device portability, MANET does not require, a pre-established network infrastructure. As a result they can be easily deployed in situations like emergency rescue and disaster management. However, there are certain issues that are inherent to MANET such as hidden and exposed terminal problem, limited bandwidth, limited processing and battery power. These issues need to be addressed for successful deployment of MANET.

Nodes in MANET are run by battery power. Sometimes, it is difficult to replace and/or re-charge the battery. Therefore, to increase the longevity of the network, the available battery power must be judiciously used. In this thesis we have proposed two techniques to enhance the lifetime of MANET. They are: *(i)* Distance Based Topology Control with Sleep Scheduling (DBSS), and *(ii)* Alternate Path based Power Management using Clustering (APMC).

DBSS is based on topology control method. In DBSS the network topology is modified by adjusting the node's transmission power. Nodes that is geographically closer to the destination node is selected as the next-hop node for routing the traffic. Nodes that are not involved in on-going transmission are put to sleep state, to conserve energy. APMC is based on transmission power management method. In APMC node disjoint alternate paths are computed. The traffic is routed through k-alternate paths, so that no nodes on a path depletes its energy at a faster rate than other nodes. A clustering mechanism is employed to control the routing activity. The network is logically divided into number of clusters. A node within each cluster is selected as cluster-head. In the absence of traffic cluster-head put the nodes on that path to sleep state to conserve energy. We have compared the proposed schemes, with existing ones through simulation. It is observed that, the proposed scheme can enhance the longevity of the network. Simulation is performed using Qualnet simulator.

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List of Acronyms

Acronym	Description
AODV	Ad Hoc On Demand Distance Vector Routing
APMC	Alternate Path-based Power Management using Clustering
BOA	Buffer Occupancy Aware
CBR	Constant Bit Rate
CBTC	Cone Based Topology Control
CLTC	Cluster Based Topology Control
CMMBCR	Conditional Max-Min Battery Capacity
COMPOW	Common Power
CTR	Critical Transmission Range
DBSS	Distance Based Topology Control with Sleep Scheduling
DCS	Direct Communication Set
DEAR	Device and Energy Aware Routing
DELAR	Device-Energy-Aware Relaying
DSR	Dynamic Source Routing
FAR	Flow Augmentation Routing
GAF	Geographic Adaptive Fidelity
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
LEAR	Localized Energy Aware Routing
LCC	Least Cluster Change
LFTC	Location-free Topology Control
MAC	Medium Access Control
MANET	Mobile Ad Hoc Network
PARO	Power Aware Routing Optimization
PLR	Power-aware Localized Routing
QoS	Quality of Service
Tpc-BS	Transmission Power Control based on Binary Search

Chapter 1

Introduction

Emergence of portable wireless communication devices and rapid growth in cellular technology have made mobile ad hoc networks (MANET) popular in civil and military applications [77, 26, 62]. The interest in ad hoc networks stem from its ability to provide instant networking solution in an area where the cellular infrastructure is either very expensive or infeasible to deploy [46]. MANETs can be deployed without the need for any fixed infrastructure like base stations. Nodes in MANET configure among themselves to establish the network dynamically. They act as a source as well as router. As a resource they generate the packet and as a router they forward the packet [55, 29]. Packets are transmitted from source to destination in multi-hops. MANETs has tremendous applications both in military (for battlefield security), and civil (medical, mobile computing, disaster recovery) [7, 24]. Applications of MANET depends on the effectiveness of routing protocol.

Nodes in MANET are powered by electro-chemical batteries whose capacity is limited. Servicing and/or replacing these batteries may not be feasible. Therefore, to extend the network lifetime some power aware mechanism has to be built into the system [56, 40, 82]. Communication and computation are the two major source of power consumption in MANET. The most energy consuming activities in MANET is the communication. Therefore, proper power management during transmission and reception will enhance the network lifetime. The transmission power of a node is directly proportional to energy consumption at the node [44, 11, 64]. Transmission power also determines the range over which a node can communicate with the neighbor [41]. Energy efficiency in MANET is not only addressed at the hardware level but also at all layers of protocol stack [68]. Energy aware routing protocols have been proposed to overcome the over-utilization of a node [79, 22]. To conserve energy, nodes in idle state are put to sleep state [30, 19]. Lifetime of MANET can be enhanced if transmission power is adjusted to a lower level [25, 23].

1.1 Issues and challenges in MANET

There has been explosive growth of interest in MANET in the last few years. To offer high-quality and low-cost services in MANET there are several technical challenges still needs to be addressed. Some of the issues in MANET are:

- Bandwidth constraint: As the medium of transmission in wireless is shared by all the nodes in the broadcast region the available bandwidth per nodes is limited in nature. The available bandwidth per wireless link depends on the number of nodes and traffic they handle.

- Lack of central-coordination: This pose a challenge in routing packet in the network. As the nodes in MANET are mobile, this lead to frequent path break. In the absence of a central co-coordinator, maintenance of path is a challenging task.

- Unstructured and/or time-varying network topology: The topology of network is unstructured. Due to mobility nature of nodes its varies with time, it is arbitrary in nature. At some time the early death of some of nodes make topology unpredictable.

- Low-quality communications: In wireless media the communication is less reliable as compared to wired medium. The network operation is easily affected by the environmental factors (weather conditions, presence of obstacles, interference of radio networks, etc), which is time varying. Thus, applications for ad hoc networks should be resilient to dramatically varying link conditions.

- Limited Battery power: Nodes in MANET are mostly run by battery, whose replacement and/or re-charging is infeasible in certain situations. To enhance network lifetime, nodes should use the minimal power during communication. Conserving nodes battery power is another challenging issue.

- Scalability: In MANET the nodes are deployed in large number in order to establish fast network set-up. So the protocol of MANET has to operate efficiently in the presence of large number nodes.

- Provisioning of QoS: The routing protocol in MANET should be able to provide certain level of QoS as demanded by the nodes. The QoS parameters can be bandwidth, delay, jitter, packet delivery ratio, and throughput.

- Security: The routing protocol in MANET must be resilient to threats and vulnerabilities. Entry of malicious node make the network vulnerable. It must have inbuilt capability to avoid resource consumption, denial-of-service, impersonation, and other similar attacks possible in MANET.

1.2 Motivation

Nodes in MANET are mostly operated by battery and they are limited in capacity. To enhance the operational lifetime of a MANET, energy conservation techniques must be applied at the hardware as well as protocol stack level. In this thesis, we have focused on energy conservation at the protocol stack. Our focus is at the network layer. That is to propose a power conservation technique which will consume less minimum power, while transmitting the packet from source to destination.

1.3 Objective of Work

In this thesis we have discussed various power efficient techniques. We propose two different techniques to conserve power. Topology control method is used in the first technique, while the second uses transmission power management method. Accordingly, we identified the objective of the thesis as given below:

- Study the existing power aware techniques.

- Propose a power efficient topology control method to reduce power consumption in MANET.

- Propose a transmission power management mechanism to enhance the MANET lifetime.

We have used Qualnet simulator and CBR traffic in our simulation.

1.4 Organization of The Thesis

Rest of the thesis is organized into following chapters:

Chapter 2: This chapter presents a review of power conservation techniques. The topology control, and transmission power management schemes to conserve energy at the network layer is discussed.

Chapter 3: A power efficient distributed protocol known as Distance Based Topology control with Sleep Scheduling (DBSS) is proposed in this chapter. It is based on topology control method. In this chapter we address to control the network topology by adjusting the transmission power. Nodes that is geographically closer to the destination node is selected as the candidate for routing the traffic. Nodes that do not take part in the on-going transmission are put into sleep state, to conserve energy. Simulation results show that DBSS has better energy conservation and lower end-to-end delay as it takes less number of hops to transmit packet.

Chapter 4: A transmission power management technique called Alternate Path based Power Management using Clustering (APMC) is proposed. In APMC node disjoint alternate paths are computed. Routing is done through alternate route, so that nodes do not depletes its energy rapidly compared to other nodes in the network. A clustering mechanism is employed to control the routing activity. A node within each cluster is selected as a cluster-head. In the absence of traffic the nodes of the path are put to sleep state to conserve energy. Simulation results show that APMC outperforms AODV in terms of energy conservation and average end-to-end delay.

Chapter 5: Conclusions, along with the future scope for research in this direction is mentioned in this chapter.

Chapter 2

Literature Review

2.1 Introduction

Mobile networks have attracted significant interest in recent years because of their improved flexibility and reduced costs [58]. They have many unique characteristics as compared to wired network. Wireless link capacity continually varies because of the impacts from transmission power, receiver sensitivity, noise, fading, and interference, in contrast to the stable link capacity of wired networks. Additionally, wireless mobile networks have a high error rate, power restrictions, and bandwidth limitations [3, 10].

According to their fixed infrastructures, mobile networks can be classified into two types: *(i)* Infrastructured networks, and *(ii)* Mobile Ad Hoc Networks (MANETs) [55]. In infrastructured mobile networks mobile nodes have wired access points in its transmission range. In contrast, MANET is self-organized autonomous networks without fixed infrastructure. In MANET nodes move arbitrarily; network experience rapid topology changes. Nodes in MANET have limited transmission ranges, hence routing path contains multiple hops.

Additionally, nodes are powered by battery, and it is unable to re-charge and/or replace battery during a mission [75, 5]. Therefore, limited battery power puts a constraint on network lifetime [71]. In the entire process of communication and computation mobile node exists in four modes as given in equation 2.1. As per the communication takes place the node undergoes transition from one state to another [24]. From Equation 2.3 it is observed that the mobile node consume least power in sleep state as compared to other state. Since the battery resource is limited so it is adviced to put the node in sleep state when it is not in use [4].

$$E_{total} = E_{path-discovery} + E_{packet-transmission} \tag{2.1}$$

$$E_{path-discovery} \propto control\ packets$$

$$E_{packet-transmission} = E_{idle} + E_{active} + E_{sleep} + E_{transient} \tag{2.2}$$

$$E_{active} = E_{recv} + E_{transmit} \ \&\ E_{sleep} \cong 0 \tag{2.3}$$

The amount of energy consumption in various modes are given in following subsection [67].

Power consumption in Transmission mode

In transmission mode, node sends data packet to other node in a network. The energy required to transmit the data packet is known as Transmission Energy, it depends on size of data packet (in Bits) [63]. The transmission energy is formulated as:

$$E_{Transmit} = (330 \times P_{length})/2 \times 10^6 \tag{2.4}$$

$$P_T = E_{transmit}/T_t \tag{2.5}$$

Where $E_{transmit}$ is the transmission energy, P_T is Transmission Power, T_t is time taken to transmit data packet and P_{length} is length of data packet in Bits.

Power consumption in Reception mode

In reception mode, node receives the data packet from other node and the energy required to receive data packet is called Reception Energy. The reception energy is given as:

$$E_{recv} = (230 \times P_{length})/2 \times 10^6 \tag{2.6}$$

$$P_R = E_{recv}/T_r \tag{2.7}$$

Where E_{recv} is the reception energy, P_R is Reception Power, T_r is time taken to receive data packet and P_{length} is length of data packet in Bits.

Power consumption in idle mode

In this mode, a node is neither transmitting nor receiving data packet. But it consumes power unnecessarily by listening to the wireless medium continuously in order to detect a packet that it should receive, so that node can switch into receive mode from idle mode. In idle mode a node does not involve in any data communication process, still it consumes a considerable amount of energy. This energy is same as the amount of energy consumed in reception mode. The power consumed in idle mode is:

$$P_I = P_R \tag{2.8}$$

Where P_I is power consumed in idle mode and P_R is power consumed in reception mode.

Power consumption in Overhearing mode

In overhearing mode a node listens to the packet that is not destined for it. The energy consumed in this mode is same as reception mode. Unnecessarily it consumes energy in receiving such packets. The Power consumed in overhearing mode is:

$$P_{Over} = P_R \tag{2.9}$$

Where P_{Over} is power consumed in overhearing mode and P_R is power consumed in reception mode.

To maximize network lifetime various power conservation techniques have been proposed to improve energy efficiency. A few of such schemes are described briefly in the next section.

2.2 Energy Conservation Techniques

Some significant work has been done to achieve energy efficiency in MANET. Different techniques are proposed in literature to improve energy efficiency. Power conservation technique can be broadly classified into two type:

- Topology Control Approach
- Transmission Power Management Approach

2.2.1 Topology Control Approach

Nodes in MANET have unpredictable mobility, due to which network experiences rapid topology changes [57]. Topology of MANET is affected by many uncontrollable factors like node mobility, weather conditions, environmental interference and obstacles and some controllable factors like transmission power, antenna direction and duty-cycle scheduling. The topology control is an effective technique for power saving [44, 83].

The topology of MANET is considered as graph with its nodes as vertices and communication links between node pairs as edges. The edge set is large possible one as normally the communication is established by node's maximum transmission power. In dense network too many links leads to high energy consumption, network throughput, and quality of services. For two nodes u and v the energy consumption of their communication grows quadratic ally with their distance.

In MANET the rate of change in routing topology with transmission power can optimize performance metrics such as network life time and throughput [57]. By controlling network topology, throughput is enhanced because of two benefits. First the interference is reduced by varying transmission radii of nodes to near one. Second more data transmission is carried out simultaneously in the neighborhood of a node. If a network has bad topology, there may be adverse effect such as low capacity, high end-to-end delay, and weak robustness to node failure [11, 49].

2.2.2 Transmission Power Management Approach

Transmission power management approach basically decides when to switch off radio transceiver of the mobile terminal to save energy [30, 19]. This power management technique is also known as sleep/power down mode. Turning the transceiver off, make the node not to listen to the channel and not take active participation in packet transferring. So turning off the station should be done with a condition not to incorporate delays in packet transmission. The synchronization should be maintained in routing so that switching off one node does not affect the performances of overall network connectivity.

A routing algorithm in MANET finds the optimal route in between source destination pairs for successful communication [37, 35]. If two nodes are coming in each other transmission range then direct communication is possible, otherwise the communication is carried out by the intermediate nodes acts as routers [27]. The stronger transmission range reduces the number of hops, whereas weaker transmission power makes the topology sparse resulting in network partitioning and high end-to-end delay due to large hop count as given in Figure 2.1. Transmission power is directly proportional to node's battery energy [1]. Increasing the transmission power make more energy consumption of a node [48, 16].

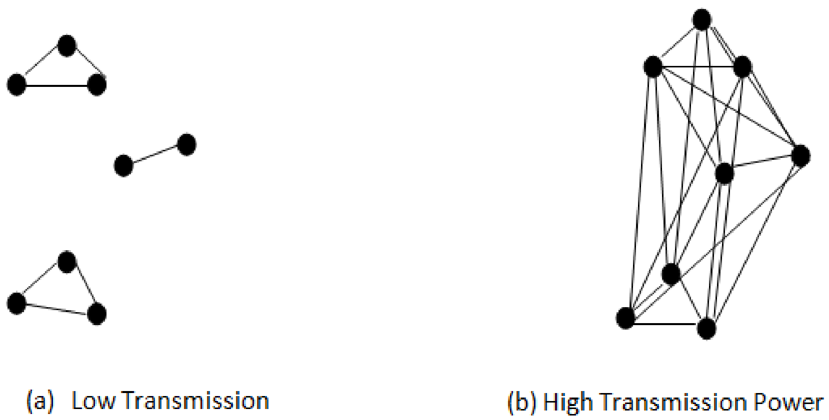

Figure 2.1: Effect of Power level on Network

Also the transmission power affects the interference and collision which may lead to retransmission result in unnecessary energy consumption. Power control is to utilize node's transmission power to reduce interference and to save energy. For energy efficient routing an appropriate transmission power of data packet at each node is decided. The fixed transmit power approach may not be feasible as it won't give guaranty of finding neighbor within a node's fixed transmission power. So in some cases the maximum transmission power is used for control message and minimum required for subsequent data reception [1].

2.3 Related Work

Under this power conservation categories various protocols have been proposed by many researchers. Some of them are explained briefly in this section.

2.3.1 XTC Protocol

XTC [74] topology control algorithm works without either location or directional information. The algorithm has three phases. In the first phase each node broadcast at maximum power, and rank its entire neighbor depending upon its link quality. The link quality could be the Euclidean distance, signal attenuation or packet arrival rate. In the second phase each node transmits its ranking results to neighboring nodes. In the final phase, each node examines all of its neighbors and decides the neighbor to be linked directly as per their ranking results. The XTC algorithm follows both symmetry and connectivity feature of topology control.

2.3.2 Location free topology control protocol (LFTC) Protocol

LFTC Protocol [61] constructs power-efficient network topology, and at the same time avoids any potential collision due to hidden terminal problem. It works in 2 phases: *(i)* Link determination phase, and *(ii)* Interference announcement phase. In link determination phase a node determines the set of its neighbors called direct communication set DCS. Each node adjusts its transmission power to a minimal value called P_{data}, to communicate with all of its neighbors in its direct communication set. Interference announcement phase avoids data collision by using appropriate transmission power $P_{control}$. This collision is resulted due to hidden terminal problem when node uses P_{data} to transmit data packets.

2.3.3 Common Power (COMPOW) Protocol

COMPOW protocol [51, 31] finds the common transmission power between two nodes in order to maintain bi-directionality between any pair of communicating nodes in a MANET. If common transmission power (P_i) is too low, a node is reachable to fraction of nodes. If P_i is very high results in high energy consumption. With high transmission power a node is able to reach directly to other nodes. Therefore the P_i value must be optimal which is small value but preserve connectivity of a network. The major drawback of COMPOW is its significant message overhead. It also tends to use higher power if nodes are unevenly distributed.

2.3.4 Cluster Based Topology Control (CLTC) Protocol

CLTC [60] framework is used for the design of hybrid topology control algorithm. There are three phases: *(i)* Phase 1, *(ii)* Phase 2, and *(iii)* Phase 3. Phase 1 for clustering algorithm, intra-cluster topology control algorithm in Phase 2, and inter-cluster topology control method is used in phase 3. Multi-hops clusters provide more flexibility in terms of trade off between efficiency and scalability.

2.3.5 Cone Based Topology Control (CBTC) Protocol

CBTC [73] is a distributed protocol based on directional information. In this protocol each node transmits with minimum power such that there is at least one neighbor in every cone of angle centered at the node. By adding reverse edge to every asymmetric link the communication graph becomes symmetric. A set of optimization is applied to improve energy efficiency without impairing connectivity.

2.3.6 Flow Augmentation Routing (FAR) Protocol

The main objective of FAR protocol [12] is to minimize the link cost of a path that will maximize the network life time. $FA(x_1, x_2, x_3)$ consider three parameters while calculating the link cost c_{ij} for the link (i, j). The first parameter is e_{ij} which is amount of energy expenditure for a unit flow of transmission between the node i and j. The second parameter is available battery energy E_i at node i. The third parameter is residual energy R_i of node i which is defined as:

$$R_i = E_i - e_{ij} \tag{2.10}$$

R_i is taken as zero if it is taken as negative. The link cost is given as:

$$c_{ij} = e_{ij}^{x_1} \times R_i^{-x_2} \times E_i^{x_3} \tag{2.11}$$

Where x_1, x_2, and x_3 are weighting factors. The cost function is directly proportional to e_{ij} and E_i. It is inversely proportional to its residual energy R_i. The route having less energy for transmission is preferred. At the same time the node having high residual energy is preferred for transmission. For this reason, FAR solves the overall optimal solution in an iterative fashion: solve the optimal route for the first time step, update node's residual energy and link costs and solve another for the next time step.

2.3.7 Buffer Occupancy Aware (BOA) Protocol

The main objective of BOA protocol [47] is that along with residual energy of a node it also considers the knowledge of buffer occupancy at the mobile hosts in choosing routes. A node may be rich in high residual energy but its queue size determines its energy remaining to transfer the next packet coming to queue. For this it takes X_i which is equal to the sum of energy required to transmit all the packets in queue of node i. Let the m^{th} packet in the buffer is to be transmitted to node j in next transmission. So for a new packet its enter to the queue and then its route sequence is decided after it reaches to the head of the queue and so the node will not know the first hop destination of the packet, i.e., j is not known for the packet. X_i is defined as:

$X_i = \sum_{m=1}^{n} e_m$ where

$$e_m = \begin{cases} e_{ij} & , \ if \ j \ is \ known \\ min(e_{ik}) \forall K \in R_i & , \ if \ j \ is \ not \ known \end{cases} \tag{2.12}$$

Where n is the number of neighbors of node i. X_i can be used to have a more accurate value of residual energy while calculating the cost metrics for a link. The BOA (x_1, x_2, x_3) protocol is defined as:

$$c_{ij} = \{e_{ij} + X_i\}^{x_1} \{R_i - X_i\}^{-x_2} E_i^{x_3} \tag{2.13}$$

Where E_i is the available battery energy and R_i is the residual energy of node i.

2.3.8 Power Aware Routing Optimization (PARO) Protocol

PARO [20] model helps to minimize the transmission power to forward the packets from source to destination. In network all the nodes are located within the maximum transmission range of each other. In packet forwarding technique one or more nodes elect to be redirectors on behalf of source destination pairs to forward the packets with reduced transmission power. In this way they decrease the overall transmission power to deliver packets in network, by increasing the operational lifetime of network.

PARO is in contrast to **AODV** protocol. AODV is based on destination-orientation. Each node has the information about its next hop nodes and its destination node. No periodic routing table exchanges are done. When a node wants to communicate with some other node then a route is set up. If no routing information is available then route discovery process is initiated [53]. Timer is required for maintaining the route freshness. Only one route reply is provided [45]. The routing table only store on a route for one destination.

PARO is applicable in number of networking environments as sensor network, home network and mobile ad hoc networks. It assumes that each radio is dynamically adjusting its transmission power on per packet basis. Instead of broadcast based approach it supports node-to-node based approach for selecting the route. It is based on the assumption that the transmission power required to transmit packet from node A to node B is same as from node B to node A with the condition that interference/fading in both the direction is same. PARO accommodates both in static and mobile environments.

2.3.9 Power aware Localized Routing (PLR) Protocol

PLR protocol [65] assumes that the source node has the location information about all the nodes and destination. It can find the link cost between its neighbors and destination. The node for which the link cost is minimum that node is selected as next hop. The same procedure is repeated for the intermediate nodes till the destination node is reached.

2.3.10 Transmission Power Control based on Binary Search (Tpc-BS) Protocol

Tpc-BS [52] algorithm is based on the selection of transmission power of a node depending on the distance between two nodes. It finds an optimal transmission power range dynamically using binary search scheme and minimize overhead in finding the same using multiple message transmission. This determined transmission power can be modified dynamically with the change of network environment.

This algorithm determines the transmission power in two phases. First if a node has to transmit data packet to target node, then it finds transmission power of target node in transmission power table. This table stores transmission power value for each node in network, which is deleted automatically after a predefined threshold time.

If a node does not find transmission power of target node, it performs transmission power finding operation using binary search scheme. To find the target node, source node broadcasts MAC control frame with specific transmission value. Reply message to the broadcasted message is considered to be the first transmission power value into transmission power table. Meanwhile, based on binary search algorithm the transmission value is replied to the target node in unicast mode. In other words next transmission power level will be half of current transmission power because the target node is in radio frequency range of the current power, so it is reduced by half of current power. If a reply packet is not received after the broadcasting of test packet, the transmission power value is doubled to original one.

2.3.11 Localized Energy Aware Routing (LEAR) Protocol

LEAR protocol [76] modifies the route discovery procedure of DSR protocol for balancing energy consumption in MANET. In DSR each node appends its identity to the header of route request message and forwards it to its destination. Intermediate nodes participate in path finding procedure. In LEAR, each node decides where to forward the route-request message to its neighbor or not based on its residual energy, E_r. When the value of E_r is higher than the threshold value E_{hr}, then it forward the route-request message, otherwise it drops the message and does not participate in route finding procedure. The destination node receive route request from nodes having higher battery level.

2.3.12 Conditional Max-Min Battery Capacity Routing (CMMBCR) Protocol

CMMBCR protocol [69] uses the threshold concept as in LEAR to find the route to destination. However in CMMBCR route having minimum power is selected if the nodes from the source-destination pair have the larger remaining battery power than the threshold value. If all the nodes of routes having the battery power less than the threshold value then max-min route is selected.

2.3.13 Device and Energy Aware Routing (DEAR) Protocol

DEAR protocol [7] explains the usage of device awareness to enhance energy efficiency in the routing. A node is assumed to be device aware if it is powered by two states: Internal battery power, and External power source. It assumes the cost of a node powered by external source is zero. The packets can be redirected to the powered node for power saving operations. An externally powered node has rich resource of power. It is capable of increasing its transmission power to a higher level so that it is easily reachable to any desired node in network in one hop distance. DEAR provides power saving by eliminating a number of hops which increases system life time, also average delay in packet receiving is minimized.

2.3.14 Device-Energy-Load-Aware relaying (DELAR) Protocol

DELAR is a cross-layer designed framework [42]. It achieves energy conservation from multiple facts including power-aware routing, transmission scheduling, and power control. It is a power aware routing protocol that incorporates device heterogeneity, residual energy information of node, and nodal load status to save energy.

It consists of heterogeneous ad hoc networks, where nodes are of two types: *(i)* B-node, and *(ii)* P-node. B-nodes, equipped with limited power sources like battery, whereas P-nodes with unlimited power. DELAR is a hybrid transmission scheduling scheme which is a combination of reservation based and contention based medium access control schemes to co-ordinate transmissions.

It is a cross layer design as it introduce mini-routing into data-link layer and Asymmetric MAC (A-MAC) scheme to support MAC layer acknowledgments over unidirectional links caused by asymmetric transmission power level between P-nodes and B-nodes. Multi packet transmission is used to improve the end-to-end delay performance.

2.3.15 SPAN Protocol

In wireless environment if a node is in low power state, it is desirable to put the node in sleep state to save energy. To decide which node to put in sleep state and which in active state, a master node is selected to maintain network connectivity. SPAN protocol [13] employs a distributed approach to select a master node. The rule is that if two of its neighbors cannot reach each other either directly or via one or two masters, it should become a master. This rule does not yield the minimum number of master nodes but it provides robust connectivity with substantial energy savings. However, the master nodes are easily overloaded. To minimize this a master node at any time withdraw as a master and gives its neighbor node a chance to become a master if it satisfies master eligibility criteria.

2.3.16 Geographic Adaptive Fidelity (GAF) Protocol

GAF [79], is an energy aware location-based routing algorithm in MANET. The entire network is divided into several square grids. Nodes use location information based on GPS to associate itself with the grid. The node having highest residual energy within each grid is selected as master of Grid. The master node is responsible for monitoring and reporting data to the destination on behalf of other nodes in the zone. Other nodes in grid can be safely put to sleep without sacrificing routing fidelity. There are three states defined in GAF: *(i)* Discovery, *(ii)* Active, and *(iii)* Sleep. Discovery state is used for determining the neighbors in the grid. Active reflects participation in routing, and sleep for turning off radio.

2.4 Summary

Nodes in MANET are powered by battery, and it is unable to re-charge and/or replace battery during an application. Therefore, limited battery power puts a constraint on network lifetime. To enhance network lifetime this scarce resource needs to be utilized in an efficient manner. In this chapter we briefly described the relevant previous work in the area of Mobile Ad hoc Networks to efficiently utilize the battery power of a node to increase the network lifetime. This work is summarized in Table 2.2. The purpose of this chapter is to provide a better background and perspective of our work.

APPROACH		PROTOCOL	GOAL
Topology Control Approach	Replace long distance communication with small energy efficient hops	• XTC Protocol • LFTC Protocol • COMPOW Protocol • CLTC Protocol • CBTC Protocol	Minimize the energy consumption by redeployment of Network Topology
Transmission Power Management Approach	Transmission Power Control	• FAR Protocol • BOA Protocol	Minimize the total transmission energy but avoid low energy nodes
		• PARO Protocol • PLR Protocol • TPC-BS Protocol	Minimize the total transmission energy while considering retransmission overhead
	Load Distribution	• LEAR Protocol • CMMBCR Protocol	Distribute load to energy rich nodes
	Use of external battery	• DEAR Protocol • DELAR Protocol	Increase transmission power of a node to reach other node as it is powered by external battery
	Sleep/ power down mode	• SPAN Protocol • GAF Protocol	Minimize energy consumption during inactivity

Figure 2.2: Classification of Energy Conservation Techniques

Chapter 3

Distance Based Topology Control

3.1 Introduction

In MANET nodes configure among themselves to establish network connectivity. Due to mobility of nodes, topology of MANET changes dynamically. Topology control is the art of coordinating node's decision regarding their transmission ranges, in order to generate a network with the desired properties such as reduction of node's transmission energy and/or enhancement of network capacity [39]. Labrador and Wightman [36] has stated topology control is an iterative process consisting of three distinct phases. First phase is known as Initialization, in which nodes use their maximum transmission power to set-up the network topology. Second phase is called Topology Construction, which constructs the reduced network topology. Third phase is called Topology Maintenance: in which the status of the reduced topology is monitored and a new topology construction phase is triggered when it requires. This cycle is repeated over the lifetime of network. Lifetime of MANET can be enhanced if transmission power is adjusted to reduced level [25, 23, 51].

Topology control is one of the important techniques for conserving energy in wireless ad hoc networks. The primary objective in topology control algorithms is to replace the long distance communication with smaller energy efficient hops, such that the resulting topology retained its connectivity. There is a tradeoff between network connectivity and sparseness [74]. In a dense network the connectivity is ensured whereas in the sparse network every node needs to be part of data communication as the connectivity is a big question.

In MANET the change of topology with transmission power can optimize the

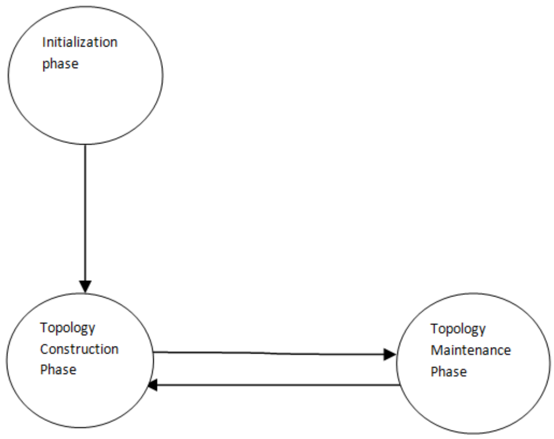

Figure 3.1: Topology Control Cycle

performance metrics such as network life time and throughput [24]. Controlling the network topology the throughput is enhanced because of the following two reasons: First, the interference is reduced by varying the transmission radii of nodes, and Second more data is transmitted simultaneously [25, 54].

3.2 Taxonomy of Topology control

Depending upon the transmission range topology control is classified into two types: Homogeneous and Non homogeneous [56]. In homogeneous all nodes in the network uses the same transmission range r. The value r is called critical transmission range and the objective is to find the value of r that satisfies the network connectivity. Nodes use different transmission range in non-homogeneous topology control mechanism, which is further classified into three types based on the type of information used to compute the topology. They are location based, direction based and neighbor based.

In location based approach accurate information about the node position is required. This approach is further divided into two categories: centralized and distributed. In centralized method a single central authority knows the location of each node and compute a set of transmitting range assignments for all the nodes [44, 54, 33]. It is simple but not scalable. On the other hand each node compute its transmission power based on the information is exchanged between the nodes in distributed approach [38, 39, 60]. Distributed approach is scalable and is adaptive to node mobility.

In direction based approach nodes do not know their position, but can estimate their relative direction from its neighbors.

In neighbor based approach, nodes can access minimal amount of information such as node ID, of their neighbors, and order them as per some criterion such as distance or link quality.

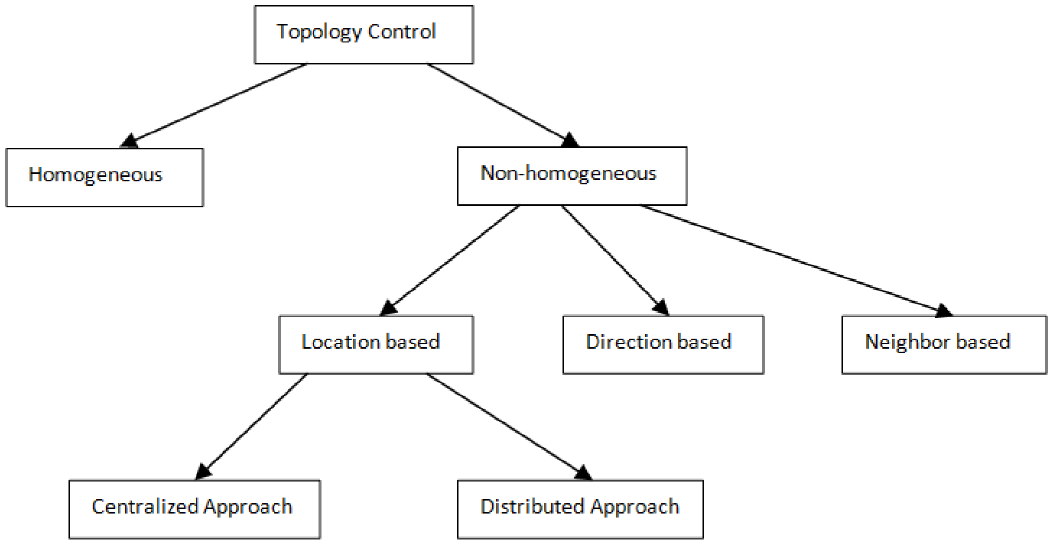

Figure 3.2: Classification of Topology Control

3.3 Distance Based Topology Control with Sleep Scheduling

In this chapter we propose a topology control approach called Distance Based Topology Control with Sleep Scheduling (DBSS) to conserve energy in MANET.

We made the following assumptions:

(i) Nodes are homogeneous i.e. they have same computational capability and initial battery power,

(ii) Nodes are equipped with GPS, so that they can obtain their locational information,

(iii) Radio interference at each node, have the capability of measuring their received signal strength.

(iv) The maximum transmission power P_{max} of all nodes are same.

(v) Symmetric communication.

Let P_{uv} denotes the minimum power required for node u to communicate directly with node v. P_{uv} is computed as given in [78], and is represented below:

$$P_{uv} = \frac{P_{max}.P_{min}}{P_r}. \tag{3.1}$$

$$P_r = P_t(\frac{\lambda}{4\pi d})^n g_t g_r \tag{3.2}$$

Where, P_{max} is the maximum transmission power of node v, P_{min} is the smaller possible receiving power of node u. P_t and P_r denote the signal power at transmitting and receiving antenna, respectively, λ denotes the carrier wavelength, d denotes the distance between the sender and the receiver, g_t, and g_r denote the antenna gains at the sender and receiver, respectively. Let $C(P_{uv})$ denote the cost associated with sending a packet from node u to v. Since we have assumed a symmetric communication $C(P_{uv}) = C(P_{vu})$.

DBSS operates in two phases: *(i)* Link determination phase, and *(ii)* Sleep scheduling phase. In the link determination phase a node, say u, determines its neighbors according to a power efficient topology control method. These neighboring nodes are called direct communication set of node u; $DCS(u)$ [61]. At the end of the link determination phase data packet transmission power of node u, $P_{data}(u)$ is determined, which is the minimal power required to communicate with all its neighbors in the set $DCS(u)$. In the sleep scheduling phase a node determines the next hop node on the path to the destination. The node which is geographically closer to the destination is chosen as next hop on the path to the destination. All the other nodes in the direct communication set are put to sleep state to conserve energy. The overall complexity of DBSS is $O(n \times d)$, where n represents the number of nodes in network and d is the average degree of nodes.

3.3.1 Link Determination Phase

In this phase a node broadcast a Hello message using maximum power P_{max}. The initial energy level of all nodes is assumed to be same [70]. Each node maintains a specific data structure called vicinity table as shown in Table 3.1. SendID records the node ID of the sender of Hello message. LocInfo: Sender-location information. DCost: cost associated with direct communication between the node and the node from which it has received Hello message. MinCost: minimum communication cost between the node and the sender of Hello message. ComNode field contain common node between SendID and the node that has received the Hello message. This field contain node ID which may be null or more than one node ID entry depending upon the path between two nodes. A null entry indicates that there exist a direct path between the node and SendID, and a valid node ID indicates that there exist energy efficient path through the node in ComNode entry. LType is marked as $'d'$ or $'i'$, where d indicates for one-hop path and i indicates multi-hop path.

Table 3.1: Vicinity Table

SendID	LocInfo	MinCost	ComNode	DCost	LType

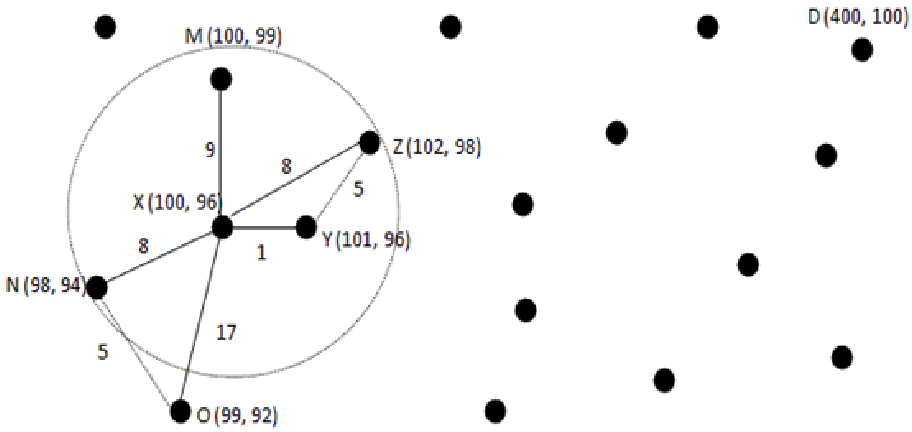

Figure 3.3: An Exemplary Network

The content of vicinity table at each node is empty at the beginning. The Hello message from a node carries the node ID and location information. On receiving Hello message the node update its vicinity table. We consider Figure 3.2 to explain the updation on vicinity table. Vicinity table at node X, after receiving Hello message from all its neighbors is shown in Table 3.3. DCost is the Euclidean distance between two nodes. For example the DCost between the nodes X and Y is computed as

$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$. Where (x_1, y_1), and (x_2, y_2) are the co-ordinates of node X and Y respectively.

Table 3.2: Vicinity Table present in hello message of node Y

SendID	LocInfo	MinCost	ComNode	DCost	LType
Y	101, 96	01	-	01	d

Table 3.3: Vicinity Table of node X

SendID	LocInfo	MinCost	ComNode	DCost	LType
Y	101, 96	01	-	01	d
Z	102, 98	08	-	08	d
M	100, 99	09	-	09	d
N	98, 94	08	-	08	d
O	99, 92	17	-	17	d

From the vicinity table a node obtain the initial information about its neighboring nodes. Using the available information it compute the common node using Algorithm 1. In wireless transmission the energy required to successfully transmit a data packet in one-hop increases with the distance [79]. Using the common node the energy expend by the node in the communication decreases.

Algorithm 1 Common node finding Algorithm

Require: Co-ordinates of 3 points: $(X(x_1, y_1), Y(x_2, y_2), andZ(x_3, y_3))$

```
1: if [(x2 − x1) × (y3 − y1)] == [(x3 − x1) × (y2 − y1)] then
2:     X, Y, and Z are collinear and Y is in between X and Z
3: end if
4: if (x1 < x2 < x3)and(cost(XY) + cost(YZ) < cost(XZ)) then
5:     Y is a common node
6: end if
```

Node X finds common node between itself and its neighbors using the Algorithm 1. For example node Y is the ComNode between X and Z, whereas N is the ComNode between X and O. After obtaining the ComNode a node updates its vicinity table. The updated vicinity table at node X is given in Table 3.4. The LType entry d indicate that there exist a one-hop path between X and the corresponding neighbor, whereas i indicate that the path between node X and its corresponding neighbor is multi-hop.

Table 3.4: Modified Vicinity Table of node X

SendID	LocInfo	MinCost	ComNode	DCost	LType
Y	101, 96	01	-	01	d
Z	102, 98	05+ 01= 06	Y	08	i
M	100, 99	09	-	09	d
N	98, 94	08	-	08	d
O	99, 92	08+ 05= 13	N	17	i

Algorithm 2 Farthest-direct-node finding algorithm

```
Require: record-list of vicinity table
i = 0
for every record in record-list do
   if record. LType == d then
      Insert record to direct-cost[i++]
   end if
   record→record. next
end for
for i = 0 to n do
   Find maximum in (direct-cost[], n)// n is the length of array
end for
for i = 0 to n do
   if maximum == direct-cost[i] then
      Find SendID of direct-cost[i]
   end if
end for
```

From the updated vicinity table a node finds the farthest direct node using Algorithm 2. Farthest direct node is the node present at a maximum distance in the node's transmission range. Then the node compute the transmission power to that node. This computed transmission power becomes the new transmission power of the node. In the above example, node M is the farthest direct node from node X. The transmission power computed by node M in the above example is 9.

For those indirect neighbor which are reachable within this new transmission range their LType field is updated to d from i. The node can directly communicate with that neighbor. For example node Z lies within the new transmission range of the node X. Therefore, its LType field is updated to d.

Finally, the modified vicinity table is updated using Algorithm 3. Table 3.5 shows the final vicinity table. At the end of the link determination phase, a node finds all of

Algorithm 3 Vicinity Table updating Algorithm

Require: record-list of vicinity table

```
for every record in record-list do
    if record. LType == i then
        Find record. DCost
        if record.DCost ≤ P_data(x) then
            LType = d //Update LType d from i
        end if
    end if
end for
```

its one-hop neighbor and its optimal power of transmission. In this phase we attempt to reduce the transmission power of a node to enhance its lifetime.

Table 3.5: Final Vicinity Table of node X

SendID	LocInfo	MinCost	ComNode	DCost	LType
Y	101, 96	01	-	01	d
Z	102, 98	05+ 01= 06	Y	08	d
M	100, 99	09	-	09	d
N	98, 94	08	-	08	d
O	99, 92	08+ 05= 13	N	17	i

3.3.2 Sleep Scheduling Phase

At the end of link-determination phase each node is having its final vicinity table. Every node starts to respond to sleep scheduling phase depending upon the information from its final vicinity table. In this phase each node utilizes its data transmission power efficiently. Nodes that is geographically closer to the destination node is selected as next hop to forward packet. Nodes not involved in routing are put to sleep state. The next hop finding algorithm is stated in algorithm 4.

Nodes calculate the distance between its direct neighbors and the destination node using Algorithm 4. It finds the node for which the distance is coming minimum. That node is considered as next hop. This node is involved in routing to forward the packet. Energy is conserved by putting the other nodes into sleep state for a predefined time. For example in Table 3.5 node X has four direct nodes Y, Z, M and N. The distance is calculated between these direct nodes and destination node D. The calculated distances are given bellow:

Algorithm 4 Next hop node finding Algorithm

Require: Final Vicinity Table of node X, Location of Destination node (x_1, y_1)

$i = 0$
for every record in record-list **do**
  if record. LType == d **then**
    Find LocInfo of node //Say (x_2, y_2)
    d=$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$// Find distance between (x_2, y_2) and (x_1, y_1)
    Insert distance[i++]
  end if
end for
for $i = 0$ to n **do**
  minimum in (distance[], n)// n is the length of array
end for
next-hop is the node for which distance is minimum

$M(100, 99) \rightarrow D(400, 100) = 300$

$Y(101, 96) \rightarrow D(400, 100) = 299$

$N(98, 94) \rightarrow D(400, 100) = 302$

$Z(102, 98) \rightarrow D(400, 100) = 298$

For the node Z the distance is coming minimum. Node X forwards the packet to node Z. Other nodes are not involved in routing. These nodes are put to sleep state using the message from node X as given in Table 3.6.

Table 3.6: Inform Message from node X to node Y

Source-ID	Msg-type	Target-node
X	Sleep, Time	$\sim Z$

In the same manner node Z finds its next hop node to the destination. It uses sleep based approach to put idle mode nodes into sleep state. Following in this way the packet successively follows the close geographic hops to reach the destination.

3.4 Simulation and Results

We compared the performance of DBSS with LFTC protocol [61] through simulation. The metrics considered for comparison are: *(i)* energy consumption, *(ii)* end-to-end delay, and *(iii)* throughput. Simulation parameters is shown in Table 3.7.

The plot for energy consumption vs. number of packets, and speed is shown in Figure 3.4 and 3.5 respectively. Energy consumption is done during transmitting and

Table 3.7: Simulation parameters

Parameter	**Value**
Area	$500 \times 500\ m^2$
Simulation Time	30 min
Number of Nodes	20
Traffic	CBR
Packet Size	512 bytes
Inter arrival time of Packets	1 sec

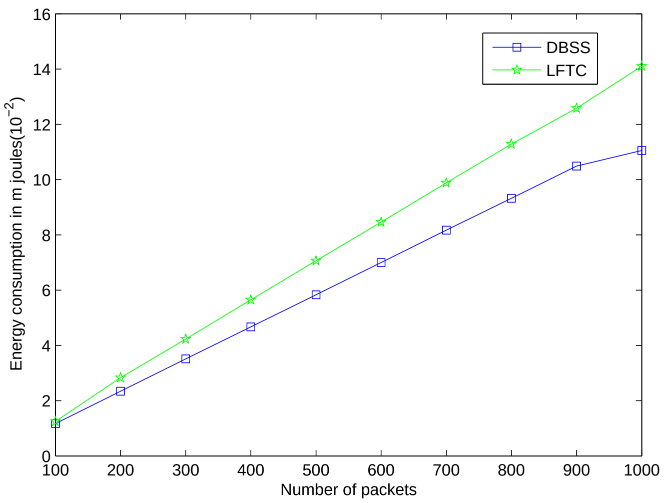

Figure 3.4: Energy consumption vs. Number of Packets

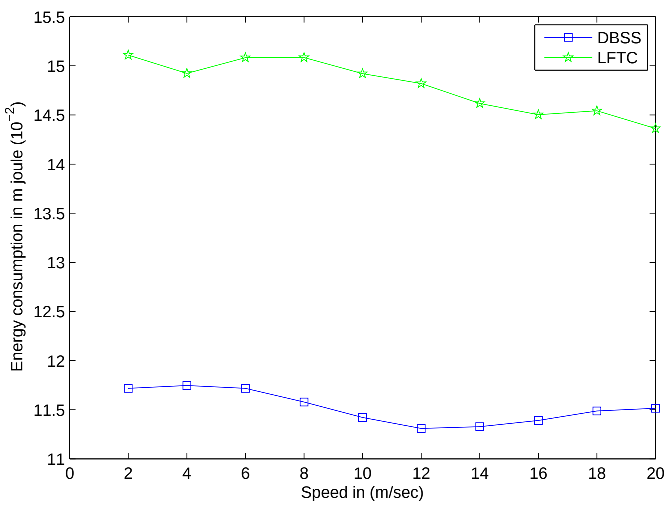

Figure 3.5: Energy consumption vs. Speed

receiving of packets as given in . It is observed from the figures that the energy consumption in DBSS is lower than LFTC. This is because in DBSS the farthest direct node is considered as the next hop node during transmission. As a result a packet is transmitted with lesser number of hops involving fewer nodes. Therefore, the total energy consumption per packet is less as compared to LFTC.

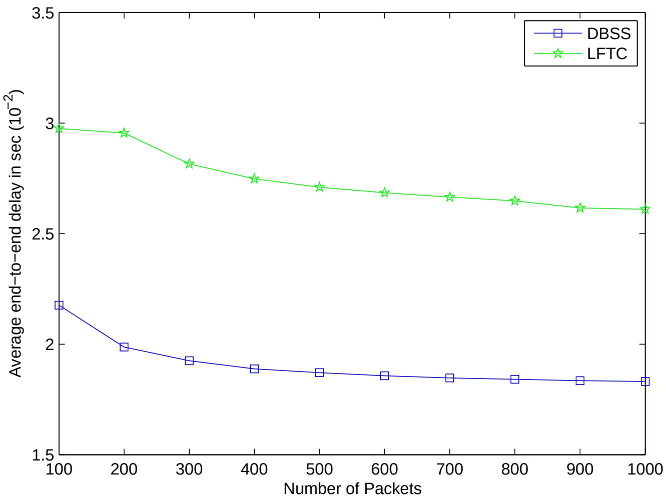

Figure 3.6: Average end-to-end delay vs. Number of Packets

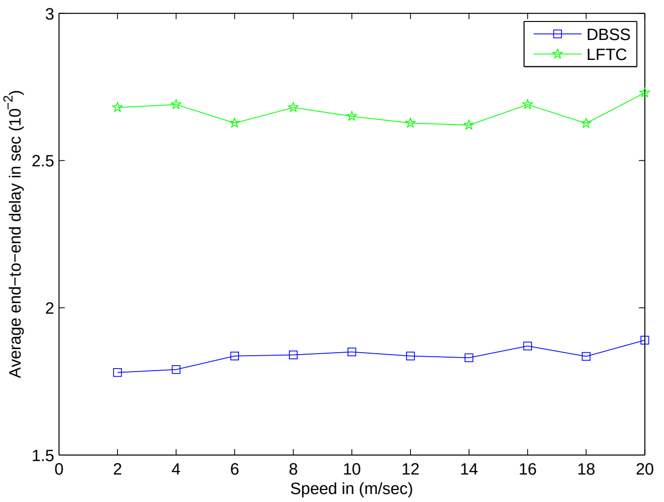

Figure 3.7: Average end-to-end delay vs. Speed

Next, we plot the graph for end-to-end delay vs. number of packets, and speed is shown in Figure 3.6 and 3.7 respectively. It is observed from the figures that the end-to-end delay in DBSS is lesser than that of LFTC. Lower end-to-end delay in DBSS is attributed to lesser number of hops in transmitting packets from source to destination.

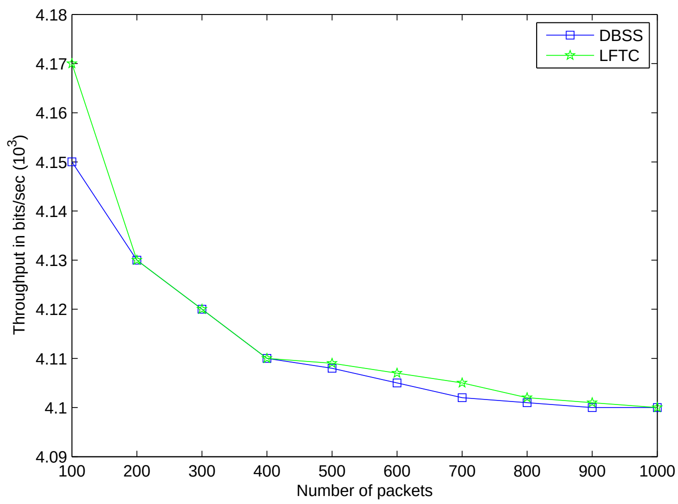

Figure 3.8: Throughput vs. Number of Packets

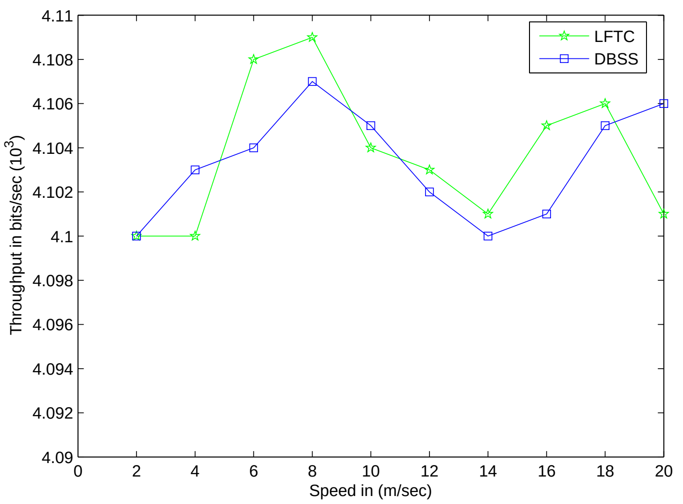

Figure 3.9: Throughput vs. Speed

Finally, the plot for throughput vs. number of packets, and speed is shown in Figure 3.8 and 3.9 respectively. It is observed from the figures that the throughput in DBSS is at least as comparable to that of LFTC.

3.5 Summary

In this chapter, we proposed a topology control approach called Distance Based Topology Control with Sleep Scheduling (DBSS) to reduce overall energy consumption in the network. In this protocol the farthest node within the transmission range that is geographically closer to the destination is selected as the next-hop node during data transmission. Nodes that do not take part in communication are put to sleep state to conserve energy. We have compared DBSS with an existing topology control scheme called LFTC. It is observed that DBSS conserve more energy compared to LFTC. The next chapter focuses on power management technique, to conserve energy in MANET.

Chapter 4

Alternate Path Based Power Management

4.1 Introduction

Power management is an important issue in MANET as devices are battery operated [28, 8]. A node in MANET needs power for performing the following task: *(i)* computing, *(ii)* listening to the channel, *(iii)* transferring and/or receiving data/control packets, and *(iv)* in sleep phase. Usually a node in MANET operates in four modes. They are: *(i)* transmission, *(ii)* receive, *(iii)* idle and *(iv)* sleep mode [29]. Among the above four state, a node in sleep state consume the least power [72, 21]. As battery power is limited in nature, to save energy it is desirable to put in sleep state as many nodes as possible [32, 59]. The main objective behind the power management approach is to trigger mobile nodes to low power mode from high power mode, when they are in idle state [17, 81, 9].

In power management, the mobile nodes are required to coordinate among themselves for communicating distributively with other mobile nodes [43, 15]. Synchronization needs to be maintained so that switching off one node does not affect the network connectivity [6, 18, 50]. A node can be in one of the following power management modes: *(i)* active mode, and *(ii)* power save mode. In active mode a node is actively participate in network activity. In power save mode, a node remain in sleep state most of time and wakes of periodically to check any pending message [19]. The power management technique in MANET facilitates to decide:

(i) Which set of nodes to perform power management,

(ii) When to switch off the active node, and

(iii) When to switch on the node from sleep state to active state.

An efficient power management technique in MANET has the following properties:
(i) Data packets between source and destination should be transmitted with minimum delay. To achieve this performance, mobile nodes remain in awake state.
(ii) The distributed algorithm is used for awakening the mobile nodes,
(iii) It should put as many mobile nodes as possible from idle state to sleep state for most of time to conserve energy.

In power managed wireless system, energy saving and performance inherently conflicting with each other. To save energy it is desirable to put the devices in low power state, while at the same time to minimize packet delivery latency the devices should remain in awake state for most of the time. So there is a trade-off between idle detection and future communication [84]. The power management approach can be categorized into two type: *(i)* Transmission control, and *(ii)* Duty cycling. Transmission control reduces energy spent in radio transmitter during communication [57]. Duty cycling reduces the energy in idle listening by allowing the radio to cycle between active and sleep period. This is an efficient means of extending system lifetime [34]. It can be accomplished by three different approaches: *(i)* TDMA, *(ii)* Scheduled contention, and *(iii)* Channel polling [80].

4.2 Alternate Path based Power Management using Clustering

In this chapter we propose a transmission power management approach called Alternate Path based Power Management using Clustering (APMC) to conserve energy in MANET.

We made the following assumptions:
(i) Nodes are homogeneous i.e. they have same computational capability and initial battery power.
(ii) The maximum transmission P_{max} of all nodes are same.
(iii) Symmetric communication.

APMC operates in two phases: *(i)* Path establishment phase, and *(ii)* Clustering phase. In path establishment phase nodes find k-node disjoint alternative path in network. In the clustering phase network is logically divided into number of clusters. Each cluster has one cluster-head which control the routing through alternative path; so that overall traffic of network is shared, and efficient network connectivity can be achieved. The overall complexity of APMC is $O(n \times d)$, where n represents the number of nodes in network and d is the average degree of nodes.

4.2.1 Path Establishment Phase

Source initiates path finding algorithm to find route to destination. The path finding algorithm is given in Algorithm 5. It provides k-node disjoint alternative paths between source destination pair. We consider Figure 4.1 to explain Algorithm 5. Source node 3 transmits control packet to its neighbor nodes. The neighbors of source on receiving this packet check for its duplicity. If this packet is received for the first time, they forward it to their neighbors, otherwise they drop the control packet. This process continues till the control packet is reached the destination.

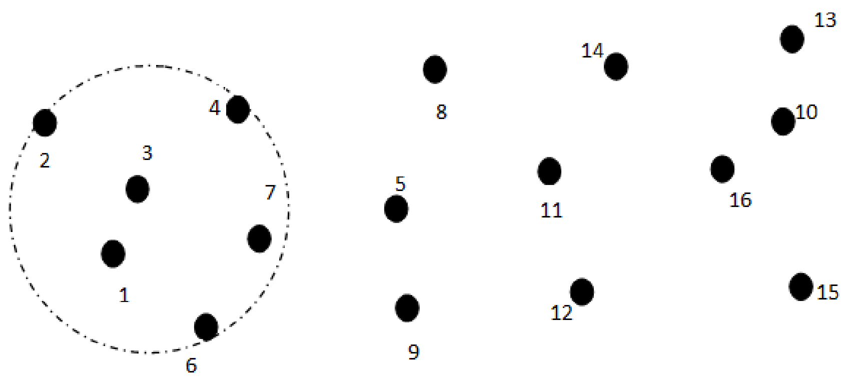

Figure 4.1: An Exemplary Network

Algorithm 5 Path Finding Algorithm

```
Source (S), Destination (D), and Intermediate (I)
S transmits control packet
I on receiving control packet check
if control packet is duplicate then
    Drop control packet
    else
    Forward packet
end if
D on receiving control packet
if control packet is first then
    Put in buffer and set delay
    else
    if delay is expired then
        Drop packet
        else
        Put in buffer
    end if
end if
D selects k-node disjoint path based on cost-metric
```

After receiving the first control packet, destination node set delay with time t. The value of t will determine the time limit up to which control packet is received at the destination node. For next subsequent packets received at the destination, t starts decreasing on each arrival of packet. At time $t = 0$ destination node finds k-node disjoint paths of network based on cost metric. For our network we consider this cost metric as min-hop count. For network in Figure 4.1 we have three distinct alternate paths. They are:

$3 \rightarrow 4 \rightarrow 8 \rightarrow 14 \rightarrow 16$

$3 \rightarrow 7 \rightarrow 5 \rightarrow 11 \rightarrow 16$

$3 \rightarrow 6 \rightarrow 9 \rightarrow 12 \rightarrow 16$

In this phase k-node disjoint alternative paths are found in source destination pair in minimum computation time. Overall network traffic is distributed among these paths to enhance network lifetime.

4.2.2 Clustering Phase

In this phase network is logically divided into number of clusters. For cluster formation Least Cluster Change algorithm (LCC) is used [14, 2]. Using this algorithm three clusters are formed in network given in Figure 4.1. They are $Cluster_1$, $Cluster_2$, and $Cluster_3$ with their cluster-head node 1, 5, and 10 respectively as shown in Figure 4.2. Cluster members for $Cluster_1$ are node 2, 3, 4, 6, and 7. For $Cluster_2$, its members are node 8, 9, and 11. Node 12, 13, 14, 15, and 16 are members of $Cluster_3$. Working of these clustering phase is illustrated in Figure 4.2.

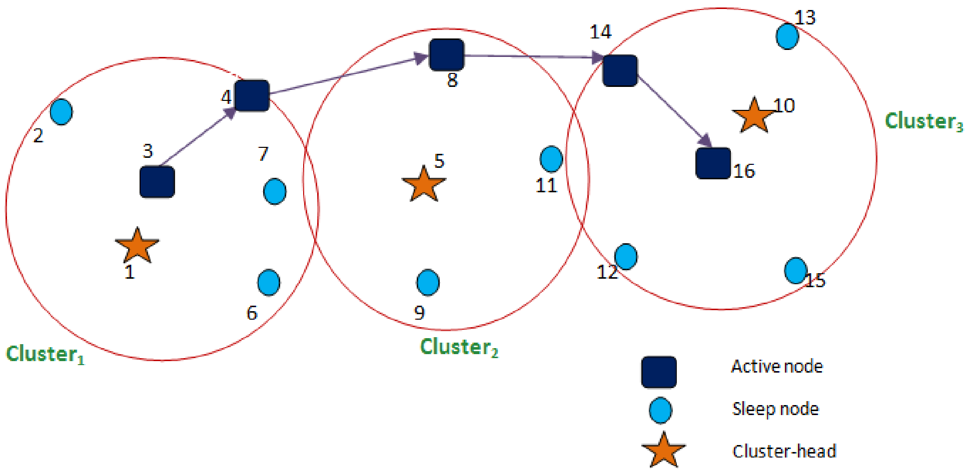

Figure 4.2: Clustering in Exemplary Network

Cluster-heads can exchange their information among them at any point of time. When packet is transmitted in one path the cluster-head put the nodes of that path in active state while others are put to sleep state. In Figure 4.2 packet is transmitted in path $3 \rightarrow 4 \rightarrow 8 \rightarrow 14 \rightarrow 16$. These nodes are actively participate in routing. Nodes of other two paths i.e. for path $3 \rightarrow 7 \rightarrow 5 \rightarrow 11 \rightarrow 16$, and $3 \rightarrow 6 \rightarrow 9 \rightarrow 12 \rightarrow 16$ are not involved in on-going transmission. Cluster-heads of these idle nodes put them into sleep state. In Figure 4.2, cluster-head of $Cluster_1$ put nodes 2, 6, and 7 into sleep state. In $Cluster_2$ node 5 being the cluster-head put nodes 9 and 11 in sleep state. Nodes 12, 13, and 15 in $Cluster_3$ are put into sleep state by its cluster-head 10. In case of heavy traffic cluster-heads balance the load of network by transferring it in different paths. By changing the state of idle mode node to sleep state overall energy consumption of network is minimized.

4.3 Simulation and Results

We compared the performance of APMC with AODV protocol [53, 66, 24] through simulation. The metrics considered for comparison are: *(i)* energy consumption, *(ii)* end-to-end delay, and *(iii)* throughput. Simulation parameters is shown in Table 4.1.

Table 4.1: Simulation parameters

Parameter	**Value**
Area	$500 \times 500\ m^2$
Simulation Time	30 min
Number of Nodes	20
Traffic	CBR
Packet Size	512 bytes
Inter arrival time of Packets	1 sec

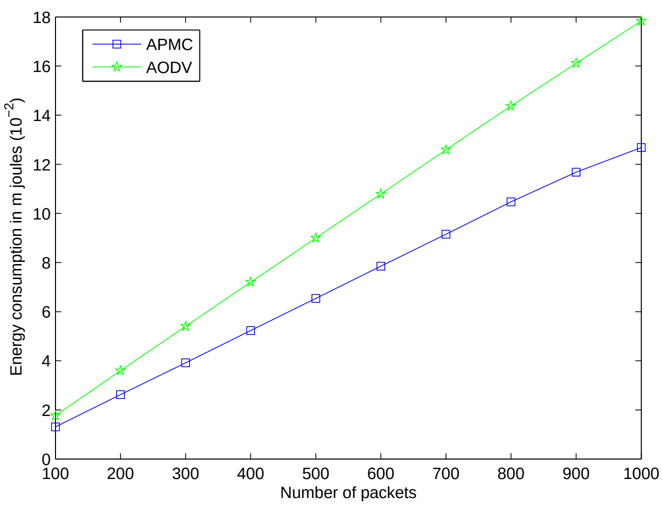

Figure 4.3: Energy consumption vs. Number of Packets

The plot for energy consumption vs. number of packets, and speed is shown in Figure 4.3 and 4.4 respectively. Energy consumption is done during transmitting and receiving of packets. It is observed from the figures that the energy consumption in APMC is lower than AODV. This is because in APMC, routing is done through

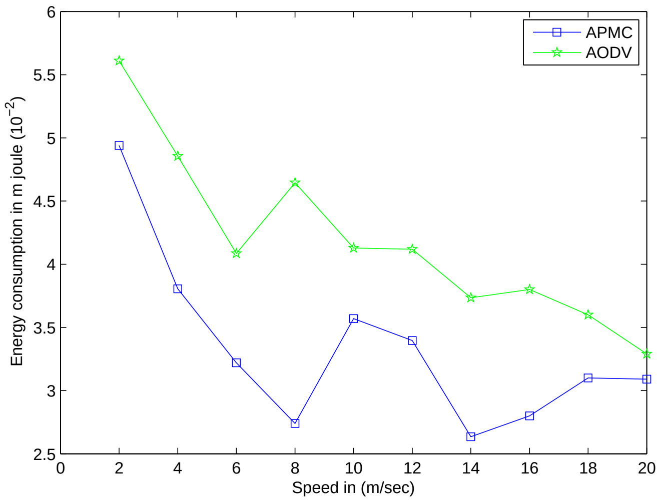

Figure 4.4: Energy consumption vs. Speed

distinct alternative nodes disjoint paths. Using load distribution approach traffic is shared among nodes in the network.

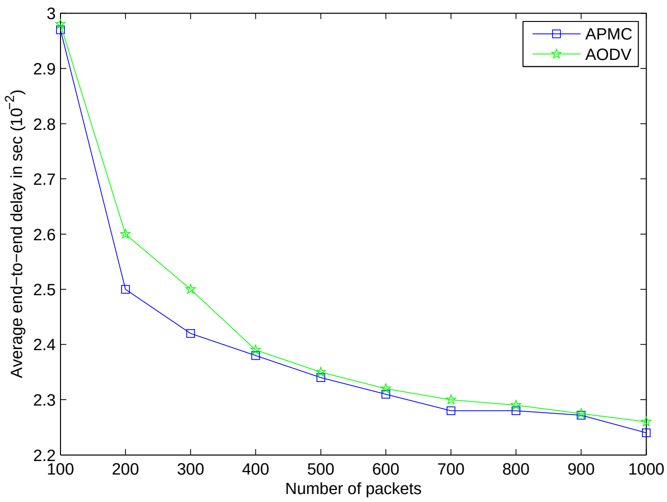

Figure 4.5: Average end-to-end delay vs. Number of Packets

Next, we plot the graph for end-to-end delay vs. Number of packets, and speed is shown in Figure 4.5 and 4.6 respectively. It is observed from the figures that end-to-end delay in APMC is lower than AODV, as traffic is shared equally among all the distinct nodes disjoint alternative paths. No node is heavily used, so the delay in

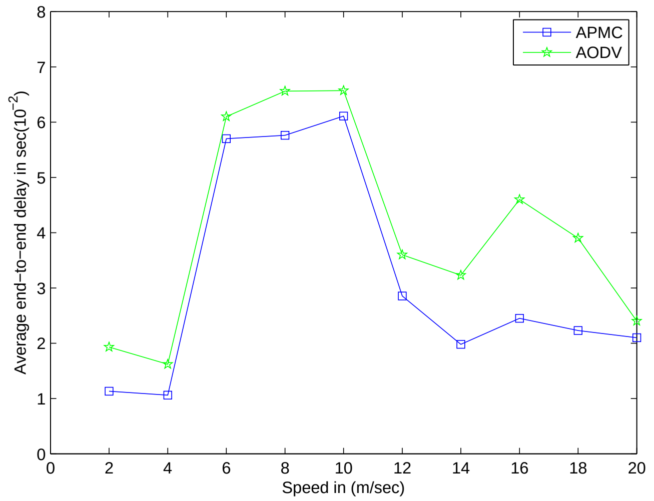

Figure 4.6: Average end-to-end delay vs. Speed

packet reception is minimized.

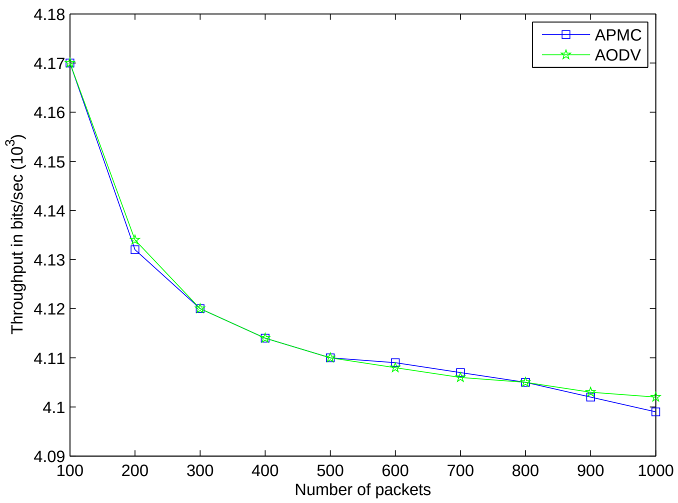

Figure 4.7: Throughput vs. Number of Packets

Finally, the plot for throughput vs. number of packets, and speed is shown in Figure 4.7 and 4.8 respectively. It is observed from the figures that the throughput in APMC is at least as comparable to that of AODV.

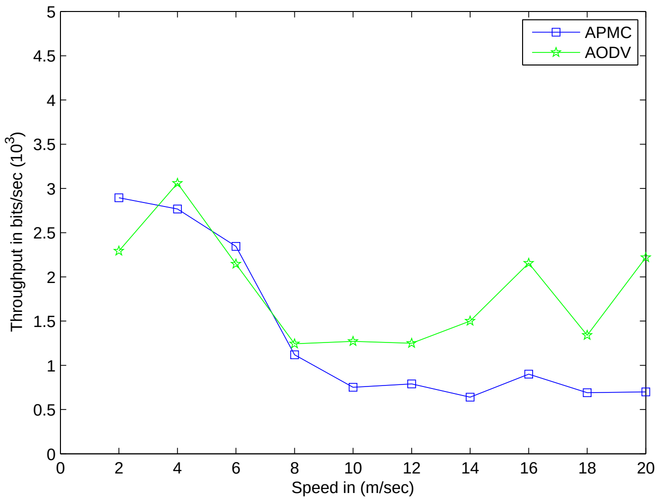

Figure 4.8: Throughput vs. Speed

4.4 Summary

In this chapter, we proposed a power management approach called Alternate Path based Power Management using Clustering (APMC) to minimize overall energy consumption in networks. In this protocol the packet is transmitted in distinct alternative nodes disjoint paths. The network is logically divided into number of clusters. A node within each cluster is selected as cluster-head. Clustering is used to control the nodes. Nodes which do not take part in the communication are put to sleep state by the cluster head. We have compared APMC with AODV protocol that uses single shortest path for data packet transmission. It is observed that APMC conserve more energy compared to AODV.

Chapter 5

Conclusions and Future Work

The only source of power supply to nodes in MANET is the battery. As there is no provision to increase the battery capacity, this limited resource must be judiciously used. Lifetime of MANET depends on the available battery power at each node. To enhance the network lifetime different energy conservation techniques have been proposed by researchers. In this thesis, we proposed two techniques to conserve energy at each node and enhance the MANET lifetime. We summarize below the contribution made in this thesis.

5.1 Contributions

5.1.1 Distance Based Topology Control with Sleep Scheduling (DBSS) Algorithm

First, we propose a distributed topology control protocol known as Distance Based Topology Control with sleep scheduling (DBSS), which operates in two phases: *(i)* Link Determination Phase, and *(ii)* Sleep Scheduling Phase. In link determination phase a node determines its one-hop neighbors retaining the network connectivity. Each node determines its transmission range to send data packet. In Sleep Scheduling phase each node finds the next hop node to transfer the packet. Nodes which do not actively participate in the on-going transmission are put to sleep state. Energy conservation in the proposed scheme depends on the duration of nodes in sleep state.

We compared DBSS with LFTC through simulation. It is observed that DBSS, performs better in-terms of energy conservation and end-to-end delay.

5.1.2 Alternate Path based Power Management using Clustering (APMC) Algorithm

Next, we propose an energy conservation scheme using power management method. This scheme attempts to manage the system power and enhance the network lifetime by enhancing the lifetime of critical nodes. Nodes which are used over and over again are called critical nodes. These nodes deplete their energy at a rate much faster than the other nodes in the network. To increase the network lifetime, these critical nodes lifetime must be enhanced. To enhance the critical node lifetime, we proposed an Alternate Path based Power Management using Clustering (APMC) which operates in two phases: *(i)* Path Establishment Phase, and *(ii)* Clustering phase. In the path establishment phase k-node disjoint route is computed. Routing is carried out through the disjoint routes. In the clustering phase the given network is logically divided into number of clusters. A node within a cluster is selected as cluster-head. Cluster-heads exchange the information among them to maintain up-to-date information about the network. When packets are transmitted in one path, the cluster-head makes the nodes in that path active while the nodes in other path are put to sleep state. In heavy traffic in network the cluster-head balance the load of network by traversing in distinct alternative paths. As the traffic is routed through multiple path, no nodes become critical in data transmission.

We compared APMC with AODV that uses shortest path in data transmission. We observed that APMC outperforms AODV in-terms of energy conservation and end-to-end delay.

5.2 Research direction for further study

Area of future work includes a power efficient technique to conserve energy by considering the transmission power of node. Transmission power of a node is directly proportional to node's battery power. For each node a threshold transmission power must be determined such that network connectivity is maintained and enhance the network lifetime. Power efficient technique can be looked at each layer of the protocol stack. Cross-layer power management, taking different layers into account is another area of research.

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Dissemination of Work

Published:

1. **Suchismita Rout**, Ashok Kumar Turuk, and Bibhudatta Sahoo, "Energy Aware Routing Protocol in MANET Using Power Efficient Topology Control Method", *International Journal of Computer Application (IJCA-2012)*, Volume:43, Issue: 5, Pages: 33-42, March 2012.

2. **Suchismita Rout**, Ashok Kumar Turuk, and Bibhudatta Sahoo, "Energy Efficient Routing Protocol in MANET using Power Management Method", 1st *International conference on Computing, Communication , and Sensor Network (CCSN-2012)*, Rourkela, Volume:3, Issue:1, Pages:94-100, November 22-23, 2012.

3. **Suchismita Rout**, Ashok Kumar Turuk, and Bibhudatta Sahoo, "Energy efficiency in Wireless Ad Hoc Network using Clustering", *Proceedings in International Conference on Information Technology (ICIT-09)*, Bhubaneswar, Pages:223-226, December 21-24, 2009.

4. **Suchismita Rout**, Ashok Kumar Turuk, and Bibhudatta Sahoo, "Energy Efficiency in Wireless Network Through Alternate Path Routing", *Proceedings in Fourth Innovative Conference on Embedded Systems, Mobile Communication and Computing, (ICEMC^2-09)*, Bangalore, Pages:3-8, July 27-29, 2009.

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Accepted:

1. **Suchismita Rout**, Ashok Kumar Turuk, and Bibhudatta Sahoo, "Review of Transmission Power Control Techniques in MANET", International Journal of Networking and Communication Engineering, January, 2013.